Alternative Fuel Light-Duty Vehicles

Summary of Results from the National Renewable Energy Laboratory's Vehicle Evaluation Data Collection Efforts

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Summary

The U.S. Department of Energy's National Renewable Energy Laboratory conducted a data collection project for light-duty, alternative fuel vehicles (AFVs) for about 4 years. The project has collected data on 10 vehicle models (from the original equipment manufacturers [OEM]), spanning model years 1991 through 1995. Emissions data have also been collected from a number of vehicles that were converted to operate on compressed natural gas (CNG) and liquefied petroleum gas. Most of the vehicles involved in the data collection and evaluation are part of the General Services Administration's fleet of AFVs. This evaluation effort addressed the performance and reliability, fuel economy, and emissions of light-duty AFVs, with comparisons to similar gasoline vehicles when possible.

Driver-reported complaints and unscheduled vehicle repairs were used to assess the performance and reliability of the AFVs compared to comparable gasoline vehicles. Driver complaints and unscheduled repairs were highest for early model AFVs, and both have decreased with each new model year. The driver complaint and vehicle repair trends indicate that AFV performance and reliability are approaching the levels of similar gasoline-fueled vehicles.

Two sources of fuel economy data were available, one from testing of vehicles on a chassis dynamometer, and the other from records of in-service fuel use. Fuel economy can vary over a wide range, depending on type of service and individual driving styles. In general, on an equivalent energy basis, the fuel economy of the AFVs in this evaluation was comparable to that of standard gasoline vehicles.

This report includes results from emissions testing completed on 169 AFVs and 161 gasoline control vehicles. Alcohol vehicles in general indicated equivalent or lower regulated emissions compared to reformulated gasoline. CNG vehicles did show significantly lower emissions than gasoline vehicles. Preliminary emissions results from vehicles that have undergone aftermarket conversion are not as promising as for OEM AFVs. Conversion emissions in many cases were higher than the vehicle emissions were before conversion.

The costs associated with owning and operating vehicles significantly affect the likelihood that fleet owners or individuals will buy them. Acquisition costs of AFVs have generally been higher than those of comparable gasoline vehicles, with CNG vehicles priced as much as 25% higher. Fuel and oil costs tend to be higher for alcohol-fueled vehicles, but lower for CNG-fueled vehicles. Maintenance costs of AFVs are expected to be marginally higher than those for similar gasoline vehicles. The included operating cost analysis allows first-order comparisons between AFV and gasoline vehicle costs.

Introduction

Overview

More than 60% of the oil consumed in the United States is used for transportation, and imported oil accounts for more than 50% of the oil supplies. In response to widespread concern about the impact of fuel consumption on our economy and the environment, Congress recognized the need to reduce our nation's dependence on imported oil. The Alternative Motor Fuels Act (AMFA) was enacted in 1988 to encourage the development and use of alternative transportation fuels (including methanol, ethanol, and compressed natural gas [CNG]), and to encourage the production of methanol-, ethanol-, and CNG-fueled vehicles. AMFA also requires the U.S. Department of Energy (DOE) to collect data to evaluate the performance, fuel economy, emissions, and operating and maintenance records of alternative fuel vehicles (AFVs). DOE designated the National Renewable Energy Laboratory (NREL) as the program manager for the light-duty vehicle data collection and evaluation projects. The Federal goverment's General Services Administration (GSA) has been required to purchase AFVs from the original equipment manufacturers (OEM) for use throughout its fleet. NREL worked with GSA to identify agencies that were using the AFVs and were good candidates for the data collection efforts.

NREL has been collecting operational, performance, maintenance, and emissions data from various light-duty vehicles, including passenger cars, vans, and pickup trucks, for about 4 years. These data have been publicly accessible through the Alternative Fuels Data Center (AFDC) electronic database, and through the National Alternative Fuels Hotline.

The light-duty vehicle program was designed to evaluate AFVs available from automobile manufacturers that operate on ethanol, methanol, or CNG. The program has recently been involved in the aftermarket conversion of a number of vehicles in the Federal fleet.

The evaluation focuses on performance and reliability, fuel economy, and emissions of the vehicles operating on the various alternative fuels. Analyses of the data collected provide useful information to fleet operators who are using or considering adding AFVs to their fleet.

Light-Duty Vehicles in the Program

The program has been collecting data from drivers of 10 light-duty vehicle models for about 4 years, spanning model years 1991 through 1995 (see Table 1). The vehicles involved in the data collection and evaluation are a subset of the AFV portion of the GSA fleet, which has grown to more than 15,000 vehicles in 1995. The AFVs studied included three CNG-fueled models, two ethanol-fueled models, five methanol-fueled models, and six gasoline-fueled models as controls. Although 1992 CNG Chevrolet pickups were recalled by the manufacturer for safety reasons, the data collected on those vehicles are included in the results presented here.

Federal agencies at various locations across the United States have participated in the data collection efforts (Figure 1). Vehicles have been operated in a wide range of "real-world" applications under varying climatic conditions and at various altitudes. The size of the data collection fleet has varied during the program as more AFVs became available and as funding for the project changed. The data collection fleet contained about 80 vehicles at the beginning and grew to a maximum of about 800 vehicles. In 1995, data were collected from 337 vehicles that operated on alternative fuels, and 146 vehicles that operated on gasoline and served as control vehicles. The mix of AFVs in the program has also varied, because GSA generally removes passenger vehicles from service after 3 years, and vans and trucks after 6 years.

The automobile manufacturers offered various passenger cars, vans, and pickup trucks that could operate on one of the alternative fuels. This data collection and evaluation effort has primarily focused on AFVs available from the OEMs. NREL, as directed by DOE, has also assisted in aftermarket conversions to enable vehicles to operate on alternative fuels (see sidebar on OEM/QVM/conversion on next page).

The vehicles in this evaluation included dedicated CNG vehicles, and flexible-fuel vehicles (FFVs) that can operate on 85% methanol (M85) or 85% ethanol (E85). In addition, the evaluation included a number of vehicles that have been converted to operate on CNG and LPG; these vehicles have been subjected to limited emissions testing.

Table 1. Light-Duty Vehicle Models in Data Collection Program

Type of Fuel	Model	Year	Total Number
Compressed Natural Gas	Chevrolet pickup*	1992	210
	Dodge Caravan	1994 1995	8 1
	Dodge Ram van	1992 1994	71 40
Ethanol	Chevrolet Lumina	1992 1993	21 34
	Ford Taurus	1994	16
Methanol	Chevrolet Lumina	1991 1993	21 29
	Dodge Spirit	1993 1994	279 13
	Dodge Intrepid	1995	8
	Ford Econoline van**	1992 1993	14 3
	Ford Taurus	1991** 1993	36 16
Gasoline	Chevrolet pickup	1993	67
	Chevrolet Lumina	1991 1993	8 39
	Dodge Spirit	1993	88
	Dodge Ram van	1992 1994	26 41
	Dodge Intrepid	1995	10
	Ford Econoline van	1993	20
	Ford Taurus	1991 1993	8 26

* Recalled for safety reasons; available data included in analysis
** Not a production vehicle; part of a vehicle demonstration fleet

Light-Duty Vehicle Summary

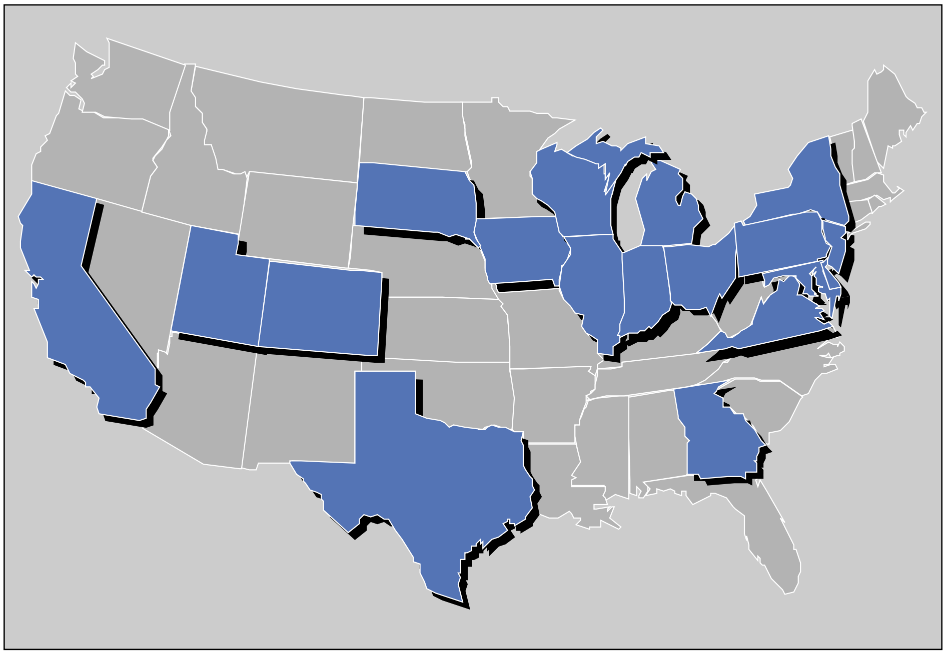


Figure 1. Locations of light-duty test vehicles

The OEM dedicated-CNG vehicles were specifically designed to operate only on CNG. A number of vehicle design modifications were required to enable operation on a gaseous fuel. These include installing high-pressure gas cylinders in place of the fuel tank, a new fuel injection system, internal engine modifications to accommodate the gaseous fuel, suspension changes to accommodate the additional weight of fuel tanks, and the addition of other fuel-management-related hardware such as pressure-relief devices.

The alcohol-fueled vehicles are called FFVs. This type of vehicle is capable of operating on gasoline alone or on various blends of alcohol and gasoline, to a maximum of 85% ethanol or methanol. The design changes required to accommodate alcohol-fueled vehicles are less extensive than those required to accommodate operation on a gaseous fuel. The FFV design modifications included incorporation of alcohol-resistant materials in the fuel system, a different fuel sensor, and a

What's the difference between an OEM, a QVM, and a converted vehicle?

There are three principal types of AFVs available to the fleet manager.

OEM Vehicles: These vehicles are designed and built by the OEMs, primarily Chrysler, Ford, and GM. All alcohol-fueled vehicles, and some CNG and liquefied petroleum gas (LPG) vehicles fall into this category. OEM vehicles are designed to have all of the engine, suspension, and chassis upgrades that an AFV needs for optimum performance and durability. They are designed to meet Federal safety and emissions standards, including crash worthiness. They have single comprehensive warranties that cover all components, including the alternative fuel ones. These vehicles tend to be most optimized for the alternative fuel.

Qualified Vehicle Modifier (QVM) Vehicles: These vehicles are similar to the OEM vehicles except that the OEM has linked up with a "qualified" conversion company to complete the final assembly of the vehicle. These vehicles generally have the same upgrades to the engine and chassis as the OEM vehicle, meet the same safety and emissions standards, and offer a single comprehensive warranty. They may have less sophisticated fuel systems than the OEM models. The final vehicle may be dedicated or bi-fuel depending on owner preference.

Aftermarket Conversions: These are gasoline vehicles that are converted by an independent company after a vehicle is sold. They do not have the engine and chassis upgrades that the other two types of vehicles offer. The conversion company provides a warranty that is separate from the OEM warranty, and generally the OEM warranty will not cover any damages caused by the installation or operation of the vehicle on the alternative fuel. Available aftermarket conversions enable vehicles to operate on CNG or LPG.

reprogrammed engine microprocessor designed to compensate for varying fuel blends.

Another option available to fleet operators is aftermarket conversion of vehicles. Aftermarket conversions involve adding equipment, after the original purchase of the vehicle, to enable operation on a fuel other than the original design fuel. Light-duty vehicles are commonly converted to operate on CNG and propane. Most CNG conversions result in bi-fuel vehicles, which means they can operate on gasoline or on the designated alternative fuel. The NREL project will convert about 900 Federal fleet vehicles, which are operating at various locations throughout the country.

Data Collected

Information related to vehicle performance and reliability, fuel economy, and emissions was collected. Two types of data were collected to evaluate performance and reliability of the AFVs and gasoline control vehicles. The first type was driver feedback on various aspects of vehicle performance. Each driver of a study vehicle was asked to fill out a card at each vehicle refueling. The card contained check-off boxes that allowed the drivers to report whether any of several problems occurred while they operated the vehicle; the cards also provided space for the drivers to make other comments about the vehicle.

The second type of performance and reliability data was vehicle maintenance and repair records. These data were initially collected by NREL from automobile dealers and repair shops that maintained the GSA vehicles. For a time, as the size of the data collection fleet increased, NREL used subcontractors to collect the maintenance and repair records for the various participating sites. NREL has also obtained GSA's maintenance and repair records for the vehicles participating in this study.

Drivers were also asked to record vehicle mileage and fuel added at each refueling. This information was used to evaluate in-use vehicle fuel economy.

Fuels Being Evaluated

Alternative Fuels

Methanol: Methanol is an alcohol produced primarily from natural gas, but it can also be derived from biomass or coal. Thus the potential domestic resource base for methanol is vast. The M85 FFVs in this program can operate on a mixture of 85% methanol and 15% gasoline.

Ethanol: Ethanol is an alcohol derived from biomass such as corn, sugar cane, grasses, trees, and agricultural waste. The domestic resource base for ethanol production is vast. The E85 FFVs in this program can operate on a mixture of 85% ethanol and 15% gasoline.

Compressed Natural Gas: Natural gas is composed primarily of methane (approximately 93%) with a mixture of other hydrocarbons. It is derived from gas wells or in conjunction with crude oil production. CNG is stored in high-pressure cylinders in a gaseous form.

Liquefied Petroleum Gas: LPG is a mixture of petroleum and natural gases, whose primary constituent is propane. It is produced as a by-product of natural gas processing and petroleum refining. It is a gas at ambient temperature and pressure, but with moderate pressure (less than 200 psi) it condenses to a liquid, making it easy to store and transport.

Gasoline

Reformulated Gasoline (RFG): RFG is gasoline developed to have lower sulfur content, reduced aromatic concentrations, and a lower vapor pressure. Oxygenates (such as ethanol, methyl tertiary butyl ether, ethyl tertiary butyl ether, or tertiary amyl methyl ether), are added to reduce carbon monoxide (CO) emissions while improving the octane quality of the gasoline. California-certified RFG was used for the emissions tests reported here.

At regularly scheduled mileage intervals, a large sample of the study fleet vehicles was temporarily removed from service to undergo emissions testing. Standard Federal emissions test procedures and qualified test laboratories were used to compare the emissions of vehicles operating on alternative fuels to those of vehicles operating on RFG.

Data were generally collected on vehicles as long as they remained in service. The quantity of data available for each vehicle depended on how the vehicles were used. GSA vehicles tended to accumulate mileage at a relatively low rate—usually less than 10,000 miles annually. Thus, many GSA vehicles were taken out of service before the vehicles were out of warranty, which limited the evaluation efforts. The data collection effort thus far has focused on the OEM AFVs, with only limited emissions data collected on conversion vehicles. The goal was to collect and provide a variety of data during the service life of the various AFVs and like gasoline vehicles in this project. This report summarizes the data collected and provides an evaluation of the AFVs in this study, and where possible provides comparisons of comparable gasoline vehicles.

The sections that follow address performance and reliability, fuel economy, and emissions for the light-duty vehicles in this program. We have included a discussion on AFV cost-related issues, although much of this information did not come directly from this evaluation effort. The final section discusses some of our data collection experiences, and provides sources for additional information on light-duty AFVs.

Performance and Reliability

The performance and reliability of light-duty vehicles can be assessed in several ways. In our program, two types of information were collected for this purpose. Drivers of the various AFVs and gasoline control vehicles were asked to provide feedback on the performance of the vehicles they drove. The drivers reported any of a number of common performance-related problems encountered while operating the vehicle. Data were also collected on the repairs required by the various vehicles to help assess their reliability. Maintenance and repair records were often difficult to obtain from repair shops and GSA. GSA does not generally track all repairs that are covered under warranty because often no cost is associated with them. The analysis of vehicle reliability is based on the data available, but we are aware that our records are incomplete.

The drivers of the study vehicles were asked to fill out a card each time they refueled the vehicle. The card included a series of check-off boxes, in which the drivers could indicate whether they had experienced any of a number of performance-related problems while driving the vehicle. The performance-related complaints included the vehicle being hard to start, the check engine light coming on, idle quality, hesitation, lack of power, engine ping, and the vehicle stalling after starting or in traffic. Table 2 summarizes the numbers of driver-reported complaints for each

Table 2. Summary of Driver-Reported Complaints* for All Vehicles in LDV Data Collection Program

Year	Fuel	Model	Vehicles in Program	Total Reported Complaints	Total Reported (< 10,000 mile)	Complaints/Vehicle (< 10,000 mile)
1991	M85	Chevy Lumina	21	435	107	5.1
	M85	Ford Taurus	36	752	395	10.9
	Gas	Chevy Lumina	8	174	62	7.8
	Gas	Ford Taurus	8	45	22	2.8
1992	CNG	Chevy pickup	210	1726	1513	7.2
	CNG	Dodge Ram van	71	962	498	7.0
	E85	Chevy Lumina	21	133	39	1.8
	M85	Ford Econoline van	14	33	8	0.57
	Gas	Dodge Ram van	26	0	0	0
1993	E85	Chevy Lumina	34	10	4	0.12
	M85	Ford Econoline van	3	0	0	0
	M85	Chevy Lumina	29	37	38	1.3
	M85	Dodge Spirit	279	221	102	0.36
	M85	Ford Taurus	16	28	19	1.2
	Gas	Chevy pickup	67	12	12	0.18
	Gas	Ford Econoline van	20	10	9	0.45
	Gas	Chevy Lumina	39	9	7	0.18
	Gas	Dodge Spirit	88	127	22	0.25
	Gas	Ford Taurus	26	25	13	0.5
1994	CNG	Dodge Caravan	8	14	15	1.9
	CNG	Dodge Ram van	40	47	43	1.1
	E85	Ford Taurus	16	6	4	0.25
	M85	Dodge Spirit	13	0	0	0
	Gas	Dodge Ram van	41	10	9	0.22
1995	CNG	Dodge Caravan	1	1	1	**
	M85	Dodge Intrepid	8	0	0	**
	Gas	Dodge Intrepid	10	2	2	**

* Includes the following types of complaints:

Hesitation	Lack of power
Check engine light	Pinging
Hard to start	Stalling after start
Poor idling	Stalling in traffic

** Insufficient data accumulated to date

vehicle model in this project. Driver-reported complaints were significantly more common for the earlier model AFVs, which have more time in service, and which in general have accumulated more miles than newer models. In addition, during approximately the first year of data collection, the study fleet was small and it was easier to obtain more complete participation in the data collection effort.

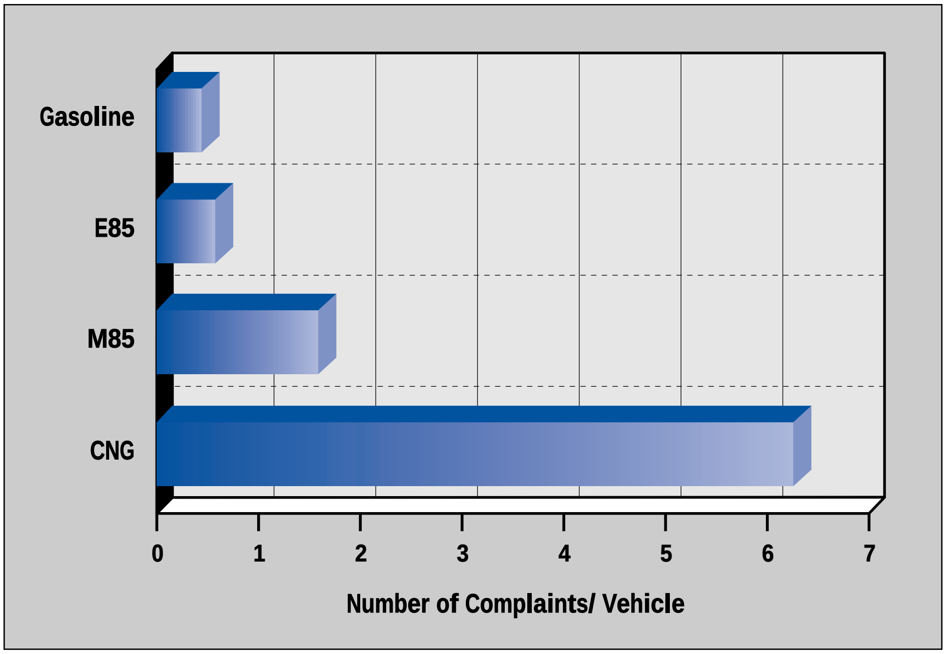


Figure 2. Average driver-reported vehicle complaints for each fuel (all program vehicles, all reports in first 10,000 miles of vehicle operation)

To ensure a more valid comparison between the different model year vehicles, only driver complaints reported in the first 10,000 miles of vehicle operation were included in the analysis presented here. Figure 2 provides an overall view of the average number of complaints per vehicle by fuel type (1995 vehicles were excluded because of insufficient data). This figure includes all the vehicles and model years for each fuel type. Table 3 gives an idea of the most commonly reported complaints. Table 2 and Figure 2 data indicate that drivers experience the least difficulty with gasoline vehicles and experience the most difficulty with CNG-fueled vehicles.

When the number of complaints is examined by model year (see Figure 3) for each fuel, however, the results paint a somewhat different picture. Again, only complaints reported in the first 10,000 miles of vehicle operation are included. More than five complaints per vehicle were reported for M85 and gasoline versions of 1991 vehicles. The number of complaints on the early model year vehicles may be high partially because the number of vehicles was small, and the project was new, so data collection and driver participation were easier to obtain. Even so, the number of complaints per vehicle has decreased with newer model year vehicles. The data for the 1993 and 1994 vehicles indicate that AFV performance, based on driver feedback, is approaching that of gasoline-fueled vehicles. In general, driver satisfaction with AFVs has increased significantly since the vehicles were first introduced to the GSA fleet.

Figure 4 provides a more detailed illustration of how complaints per vehicle have changed with newer model vehicles. This figure shows the average number of various performance complaints for two model years of CNG Dodge Ram vans. For 1992 vehicles, the average number of

Table 3. Most Commonly Reported Driver Complaints by Fuel*

Complaint	CNG	M85	E85	Gasoline
Hesitation	18%	13%	32%	
Check engine light		9%		
Hard to start	17%	9%		20%
Poor idling	23%	45%	14%	47%
Lack of power	11%	10%	12%	14%
Stalling after start	13%		13%	
Stalling in traffic			11%	

* Values are percent of total complaints for all program vehicles operating on each fuel

each type of complaint was less than two, with vehicle hesitation and lack of power being the most common complaints. Drivers of 1994 CNG vans reported fewer than 0.5 complaints per vehicle for all categories. The experience gained from the earlier vehicle model has apparently resulted in significantly improved performance in the newer CNG model.

One common performance-related complaint that CNG-fueled vehicle drivers reported (beyond choices on the data card) was a lack of range. Some drivers reportedly limited their use of these vehicles for fear of running out of fuel. This continues to be a factor when considering dedicated CNG vehicles, particularly in areas with a limited fueling infrastructure.

Figure 5 shows the complaints per vehicle for the 1993 Chevrolet Luminas operated on gasoline, M85, and E85. All performance areas received fewer than one complaint per vehicle (note x-axis scale compared to Figures 2 and 4), regardless of fuel. This indicates that in general the drivers of this vehicle were satisfied with performance. Similar results were seen for other newer model vehicles when a direct comparison could be made between the alternative fuel and gasoline.

The assessment of vehicle reliability has been based on the maintenance and repair records available for the various vehicles in our program. Maintenance and repair characteristics of any vehicle are significantly influenced by factors such as the duty cycle and the rate of mileage accumulation. Also, in this program

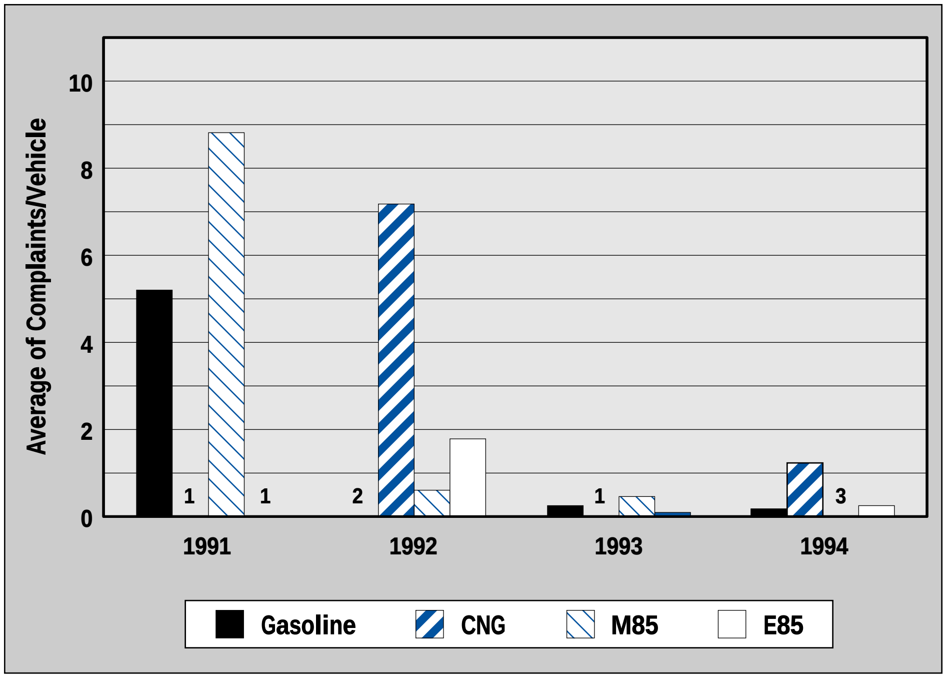


Figure 3. Driver-reported complaints by fuel type (in first 10,000 miles of vehicle operation)

1 No CNG vehicles in 1991 or 1993 and no E85 vehicles in 1991

2 No gasoline vehicle complaints reported in 1992

3 No M85 vehicle complaints reported in 1994

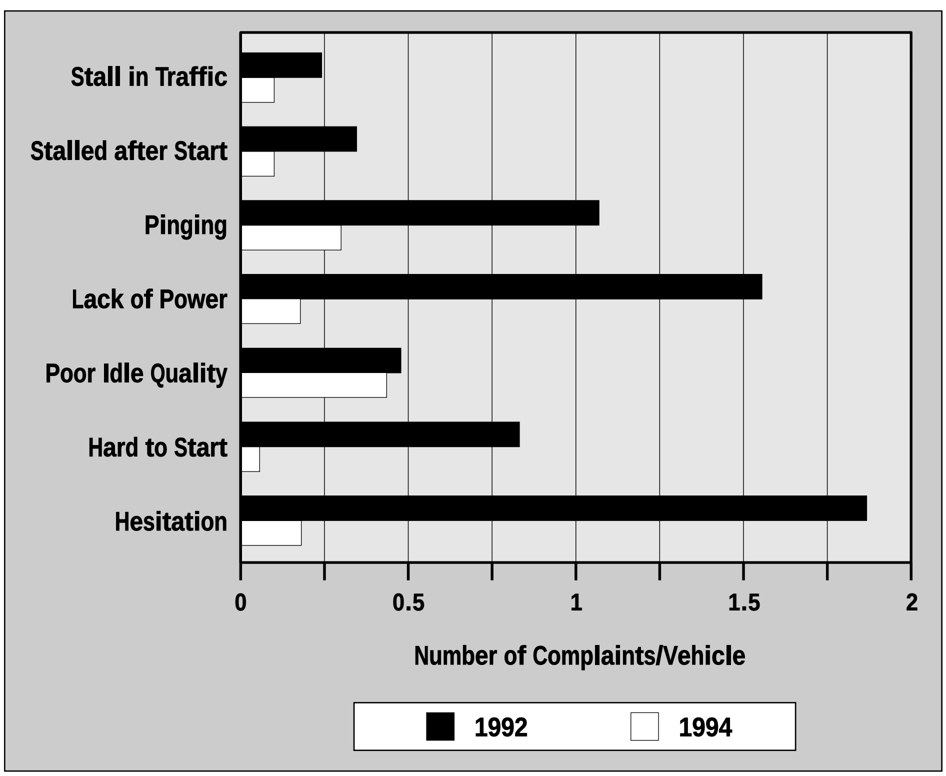


Figure 4. Driver-reported complaints per vehicle for CNG Dodge Ram van (in first 10,000 miles of vehicle operation)

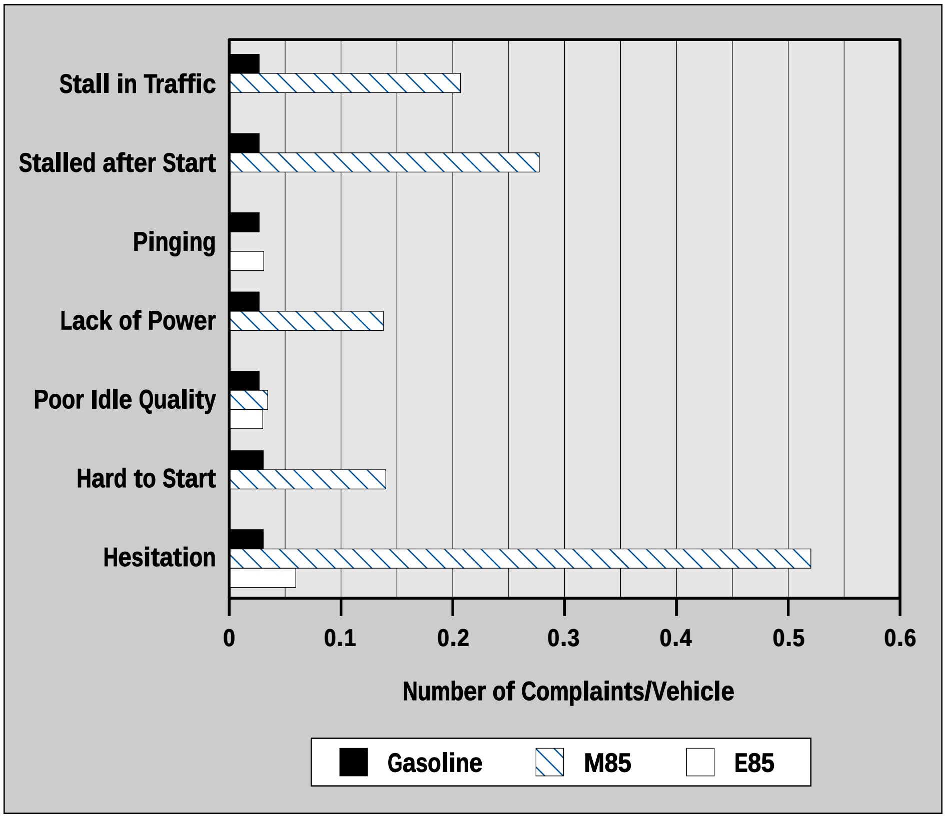
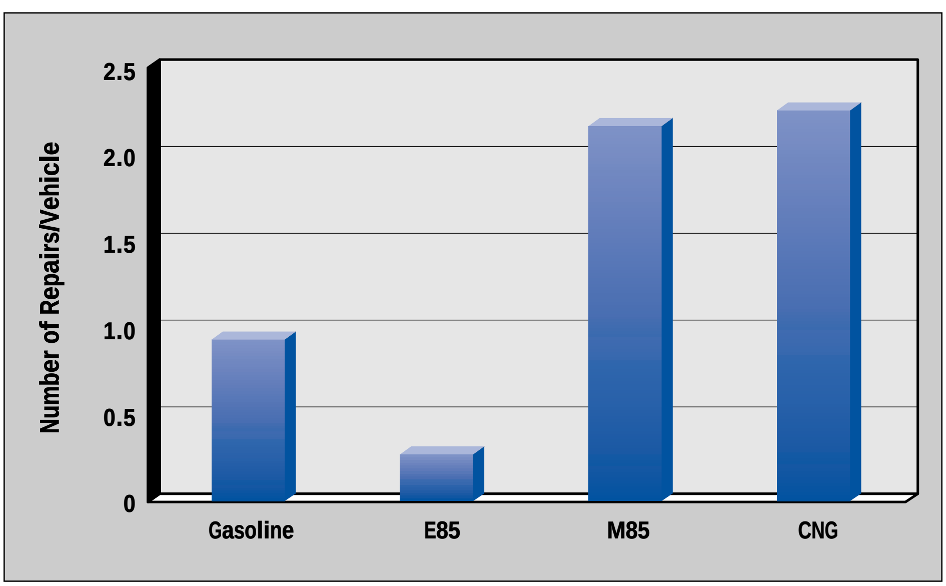


Figure 5. Driver-reported complaints per vehicle for 1993 Chevrolet Luminas (with fewer than 10,000 miles on vehicles)

Figure 6. Average number of unscheduled repairs by fuel type (repair data are very limited for E85 vehicles)



some early model AFVs were prototypes or included components that were still developmental. With these factors in mind, to evaluate the reliability of the vehicles, we assessed the number and type of unscheduled repairs. The term unscheduled repairs implies breakdowns or problems that require servicing and affect vehicle availability. Most unscheduled repairs for the AFVs involved the fuel or fuel system, and, as with the performance problems, they were more numerous in the early model year AFVs (1995 vehicles were excluded because of insufficient data).

The unscheduled repairs per vehicle are shown in Figure 6, which includes data for all vehicle models and years by fuel. The CNG and M85 vehicles have averaged about 2.5 times the number of unscheduled repairs as gasoline vehicles. Although shown in this figure, the repair data for the ethanol vehicles have been very limited, and are not sufficient to enable a valid assessment of their reliability.

When the analysis focused on unscheduled repairs in vehicle systems affected by alternative fuels (such as fuel system, engine, and exhaust system), the early model CNG and M85 vehicles were found to have significantly more repairs per vehicle than the gasoline vehicles (see Figure 7). For the 1992 CNG vehicles, the most common fuel-related repairs included fuel tank (replacement or additions), fuel lines and valves, fuel injectors, and fuel pressure regulators. Reports of injector repairs are nearly gone, and the number of fuel tank and valve and line repairs has decreased for 1994 CNG vehicles. The most common repairs for the 1991 M85 vehicles included fuel pumps, fuel injectors, fuel filters, and fuel senders and gauges. Reports of similar repairs have decreased with each new model year and are significantly lower than for the 1991 M85 vehicles.

In evaluating Figure 7, it is important to keep in mind that the earlier vehicles have accumulated more mileage, and are likely to have reported more repairs, than the 1994 vehicles. However, when comparing the same model year, the AFVs tend to have more fuel- and fuel-system-related repairs.

The mileage and in-service time vary for vehicles of different model years, but unscheduled repairs appear to be decreasing for newer AFVs. Figure 8 displays the average number of unscheduled repairs that have been reported in the first 10,000 miles of vehicle operation. The gasoline vehicles reported about 1.25 unscheduled repairs per 1992 model vehicles to about 0.6 per 1993 and 1994 models. The 1992 CNG vehicles reported about 50% more unscheduled repairs than the gasoline vehicles, and the 1992 M85 vehicles reported about 40% more. However, the average number of unscheduled repairs to the 1994 CNG and the 1993 and 1994 M85 vehicles dropped significantly, to be slightly lower than that for gasoline vehicles of the same model year.

The decline in unscheduled repairs for vehicles reported with fewer than 10,000 vehicle miles probably results both from vehicle design changes and from repair technicians' increased familiarity with AFVs. In most cases unscheduled fuel-related and other repairs were covered by warranty, so excess downtime was the real cost to fleet operators. But the repair trends indicate that unscheduled repairs of AFVs have decreased and are approaching the levels seen in similar gasoline-fueled vehicles.

The data collected on light-duty AFVs in this program indicate that both the performance and reliability of the AFVs have improved with each new model year.

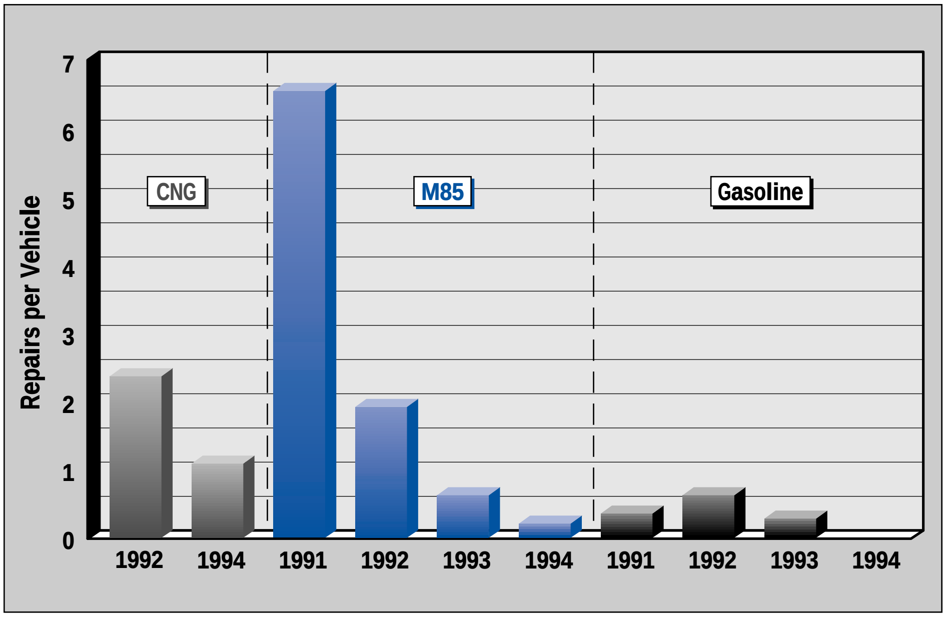


Figure 7. Average number of fuel-related unscheduled repairs by model year

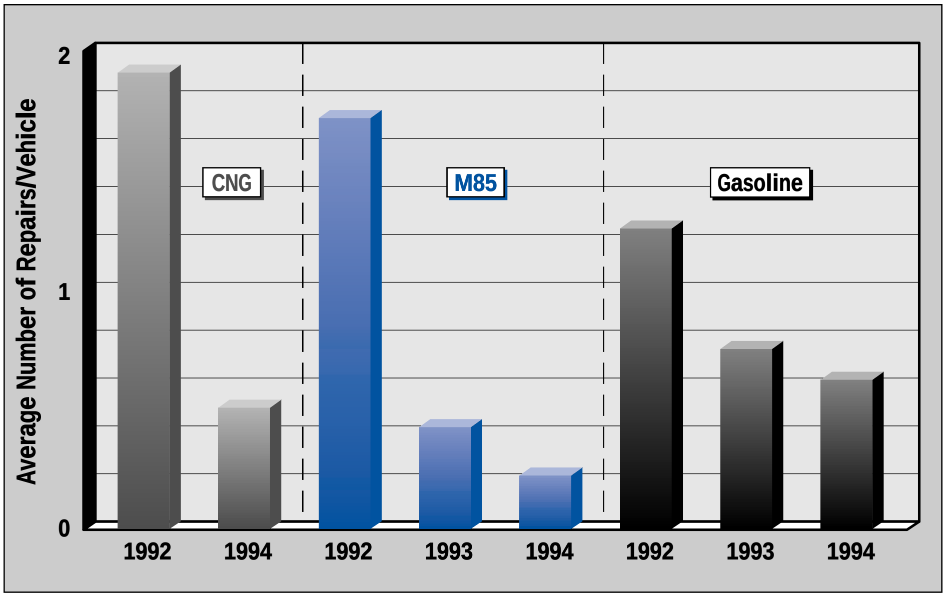


Figure 8. Average number of unscheduled repairs reported (in first 10,000 miles of vehicle operation)

Fuel Economy

Two sources of fuel economy data were available, one from testing vehicles on a chassis dynamometer (during emissions tests), and the other from analyzing refueling records. The alternative fuel consumption was converted to gallons of gasoline equivalent (GGE) for both sets of data so they could then be compared to fuel economy data for gasoline. The conversion is performed by comparing the potential energy contained in each of the alternative fuels. Table 4 lists the energy content (in Btu) of each typical commercially available fuel, and the GGE correction factor for each fuel. The energy content for CNG is listed in Btu/lb, because CNG is a gas and cannot be directly related to the Btu/gal measure for gasoline.

Fuel economy information was obtained on each vehicle during emissions testing on a chassis dynamometer. Each vehicle followed the Federal Test Procedure (FTP) using the Urban Driving Dynamometer Schedule (city cycle) and specially blended emissions test fuels. A number of similar vehicles are tested and measurements are then averaged to obtain a single value. Average values from vehicles whose emissions were tested are provided in the column labeled “mpg” in Table 5. Each alternative fuel’s average mpg was within 1 or 2 mpg of the average mpg obtained with RFG.

In-service fuel economy data were calculated by using refueling records maintained in DOE’s AFDC at NREL. Vehicle use varies considerably because of individual driving style and other factors such as type of driving (stop-and-go city, highway, deliveries, or some combination of all three), and climate.

Calculations of in-use fuel economy were further complicated in the case of the alcohol-fueled vehicles. The FFVs could be fueled with either alcohol or gasoline at any refueling. When this occurred, the gasoline would mix with the alcohol fuel remaining in the tank, creating a unique blend. To account for this, the in-use fuel economy for the alcohol-fueled vehicles was based only on instances where the vehicles were refueled three consecutive times with alcohol fuel.

In-service fuel economy is also shown in Table 5. The in-service low and high mpg values are presented for each AFV and comparable gasoline control vehicle. These values represent the ranges of fuel economy obtained by the various vehicles involved in this light-duty vehicle study. Some vehicles have a wide

Table 4. Typical Fuel Energy Content and Conversions Data

	Energy Content	
Fuel	**Lower Heating Value (Btu/gal)**	**Gallon of Gasoline Equivalent (GGE)***
Gasoline	115,400	1
Ethanol (E85)	81,500	1.42
Methanol (M85)	65,100	1.77
	Btu/lb	
CNG	20,356	N/A

* Divide gallons of fuel by this factor to get GGE

Table 5. Fuel Economy Results from Emissions Tests and In-Use Fueling Records
(All Alternative Fuel Values in Miles per Gallon of Gasoline Equivalent)

Vehicle Model	Fuel Type*	Model Year	MPG**	In-Use MPG	
				Low	High
Chevrolet pickup	CNG	1992	12.0	7	14
	Gasoline	1993	14.0	10	16
Chevrolet Lumina	E85	1992, 1993	20.2	9	29
	M85	1993	19.5	14	30
	Gasoline	1993	19.1	14	28
Dodge Caravan	CNG	1994	not available	8	13
Dodge Ram van	CNG	1992, 1994	12.5	8	15
	Gasoline	1992, 1994	13.5	6	17
Dodge Spirit	M85	1993, 1994	22.3	15	31
	Gasoline	1993	24.0	21	32
Ford Econoline***	M85	1992, 1993	13.9	8	19
	Gasoline	1993	15.0	9	18
Ford Taurus	E85	1994	22.0	11	28
	M85	1993	20.7	18	31
	Gasoline	1993	21.4	21	34

* Reformulated gasoline was used for all gasoline emissions tests.
** Average fuel economy measurements during emissions tests.
*** Not a production vehicle, part of a vehicle demonstration fleet.

mpg range, which is most likely the result of the variability in type of driving and driving styles. In most cases, on an equivalent energy basis, the vehicles operating on alternative fuels achieve fuel economy levels similar to standard gasoline vehicles.

Emissions

Emissions measurement is the single most comprehensive part of the test program for light-duty vehicles. The effort undertaken by NREL is also the most extensive and carefully controlled study of AFV emissions of which we are aware. The study focused primarily on vehicles from the OEMs, but a small-scale investigation of emissions from converted vehicles was also undertaken. The preliminary results of both efforts is discussed below.

Emissions Testing Procedures

To evaluate the emissions performance of AFVs, a large number of randomly selected OEM vehicles were tested using standard FTPs, the same procedures used by the Environmental Protection Agency (EPA) to certify vehicle emissions performance. These procedures are far more complex and representative of real-world conditions than a typical dealership or state emissions inspection station can perform, and include emissions taken while the car is driven over a simulated city route. The primary regulated emissions compounds, carbon monoxide (CO), oxides of nitrogen (NO_X), hydrocarbons (HC), and non-methane hydrocarbons (NMHC) were measured. Carbon dioxide (CO_2), which is currently not regulated, but which is a "greenhouse" gas, was also measured. Because HC emissions are really a class of compounds, rather than a single compound, the HC emissions from a representative sample of vehicles were broken down into their more than 300 constituent compounds to evaluate their toxicity and ozone- (smog-) forming potential.

Table 6. Vehicles with Extensive Emissions Testing Completed

Vehicle Model	Year	Model Type	Number of Vehicles	Number of Tests
Chevrolet Lumina	1991	Standard	8	25
	1992	E85 flexible-fuel	13	59
	1993	E85 flexible-fuel Standard	12 16	42 23
Dodge B250 van	1991	Dedicated CNG	2	2
	1992	Dedicated CNG Standard	36 22	50 25
	1994	Dedicated CNG Standard	14 25	14 35
Dodge Spirit	1993	M85 flexible-fuel Standard	76 72	319 126
Ford Econoline van	1992	M85 flexible-fuel	13	53
	1993	M85 flexible-fuel Standard	3 18	9 23

Vehicles were taken from GSA and other government fleets. In all cases, vehicles were tested by one of three laboratories in the country. These laboratories were carefully selected based on their proven ability to perform high-quality testing that conforms to EPA's procedures. Specially blended fuels were used for all testing, including for the gasoline "baseline" fuel. For the gasoline fuel, California Phase 2 reformulated gasoline (RFG) was chosen because it represents the state of the art of gasoline fuel today. If alternative fuels are to compete successfully, they must compete with the best gasoline fuels.

The goal of the ongoing program is to test vehicles at regular mileage intervals and to test the latest AFV technologies as they become available. The results presented here are based on analysis of the first round of testing on the vehicles.

OEM Vehicle Emission Test Results

The OEM vehicles tested were ethanol and methanol FFVs, dedicated CNG vehicles, and similar control vehicles running on RFG. To compare emission levels at various fuel blends, FFVs were tested on three fuels: a mixture containing 85% alcohol and 15% RFG, a mixture containing 50% alcohol and 50% RFG, and 100% RFG. Vehicles that operate on CNG are tested on CNG, and the results are compared to similar gasoline vehicles that run on RFG. All the test fuels used in the emissions testing were specifically blended for this program. The results presented in this report are based on 548 emissions tests conducted on 169 AFVs, and 257 emissions tests conducted on 161 gasoline control vehicles. These totals include tests on multiple fuels, and repeat tests on individual vehicles.

Emissions testing has been conducted on several vehicle models, but the results presented in this report are only for the models with fairly extensive testing completed. Table 6 lists the vehicles included in this analysis and the number of emissions tests completed. The vehicles include Dodge Spirits (M85), Chevrolet Luminas (E85), Ford Econoline vans (M85) and Dodge B250 vans (CNG). The average exhaust emissions for NMHC, CO, NO_X, and CO_2 are shown in Figures 9–12 for each model.

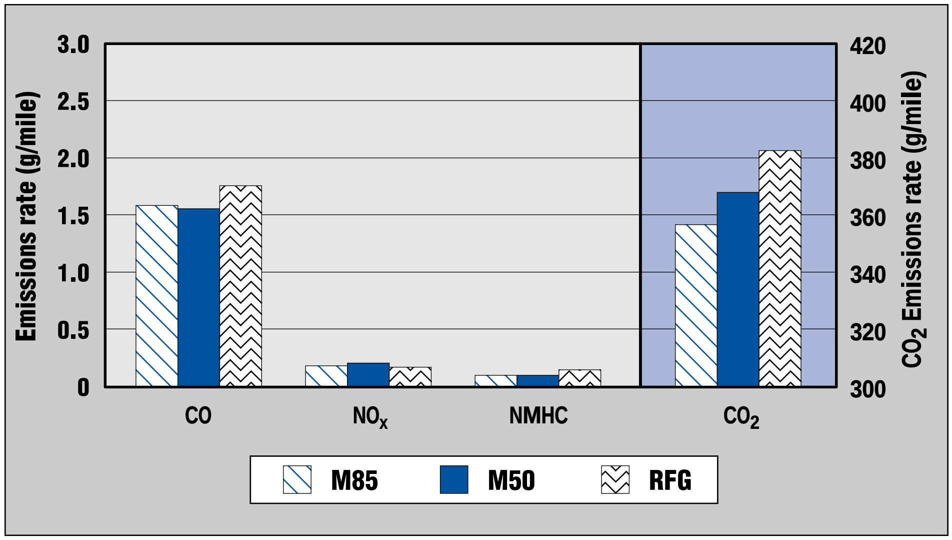


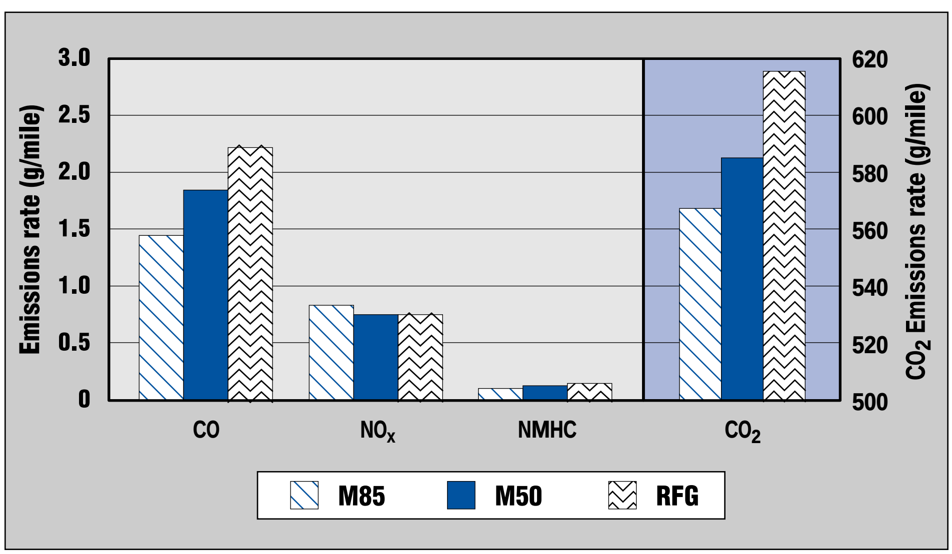
Figure 9. Emissions results from Dodge Spirits

The results indicate that the alcohol-fueled vehicles in general show reduced or equivalent emissions of regulated compounds compared to RFG, although they do have other environmental benefits discussed later in this section (see Figures 9–11). The ethanol Lumina had the largest reductions of the alcohol vehicles, averaging about 15%–20% lower regulated emissions than RFG.

The CNG vehicles showed significantly lower emissions of the regulated exhaust pollutants than did the standard gasoline vehicles (see Figure 12). NMHC emissions were approximately 64% lower, CO approximately 43% lower, and NO_X about 31% lower than the levels observed for the gasoline vehicles.

A more thorough analysis of the HC emissions to determine the toxicity and smog-forming potential of the various constituent compounds yielded some important results. The HC profiles for the alternative fuels were much different than those for RFG. For example, HC toxins, such as benzene and 1,3-butadiene were as much as 80% lower for alcohol fuel tests and approximately 95% lower for CNG tests than for the same vehicle on RFG. On the other hand, formaldehyde and acetaldehyde emissions were increased for methanol and ethanol, respectively, and were generally lower for CNG. Again, these results are all compared to RFG.

Figure 10. Emissions results from Ford Econoline vans



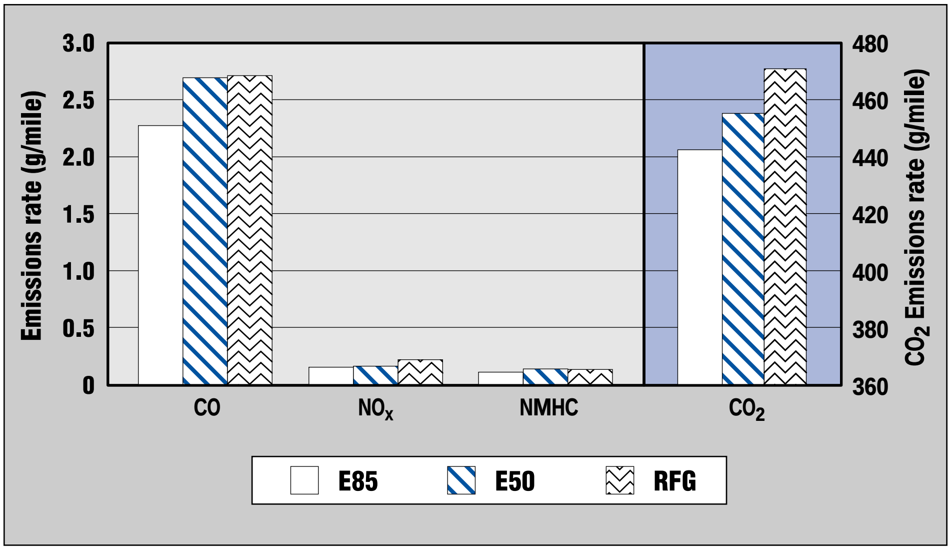
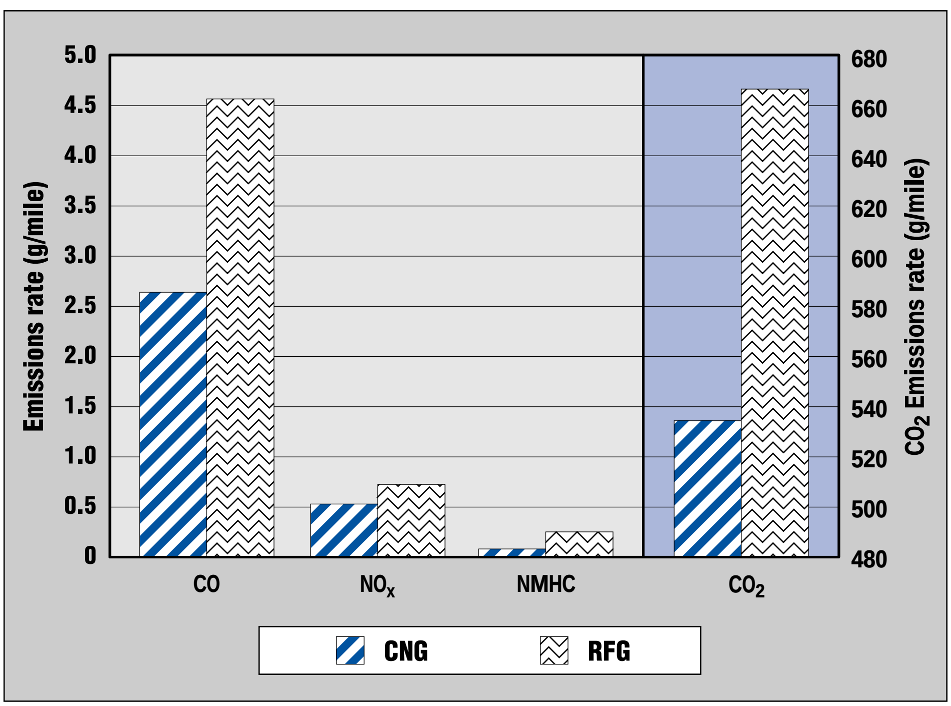


Figure 11. Emissions results from Chevrolet Luminas

Figure 12. Emissions results from Dodge B250 vans



HC analysis also allows a relative comparison between fuels on the potential for exhaust HCs to react in the atmosphere to form ozone, more commonly known as smog. The preliminary results indicate that the ozone-forming potential was reduced for each alternative fuel compared to vehicles running on RFG. The results are shown in Figure 13. Ozone-forming potential was reduced approximately 25% for the ethanol vehicles, up to approximately 50% for the methanol vehicles, and approximately 80% for the CNG vehicles.

Carbon dioxide is not a regulated exhaust emission, but studies have linked CO_2 emissions to the greenhouse effect and global climate change. Figures 9–12 show that all alternative fuels tested produced lower CO_2 emissions.

Conversion Vehicle Emissions Test Results

Limited emissions testing was completed on gasoline vehicles converted to operate on CNG and LPG. Thirteen CNG conversions and three LPG conversions were tested. The same kind of testing as described above for the OEM vehicles was conducted on the conversions. Each vehicle was tested on RFG before conversion, then emissions tested on RFG and either CNG or LPG following conversion.

Emissions levels of all three regulated emissions (NMHC, CO, and NO_x) were either improved or unchanged on only two of the 16 vehicles when running on the alternative fuel. CNG conversions generally showed a significant reduction in NMHC emissions, but an increase in CO or NO_x, or both. The emissions results on the CNG conversions are shown in Table 7. These results contrast with those from the OEM CNG model discussed above, in which substantial across-the-board emissions benefits were realized. The three LPG conversions tested showed increased emissions on gasoline after conversion, and mixed results on LPG. The increased emissions on gasoline after conversion are likely a result of the kit design or installation rather than of the fuel. No comparison between CNG and LPG is possible because the conversion kits used for CNG and LPG were dramatically different in design and operating principles.

Carbon dioxide emissions decreased by approximately 20% for CNG and 10% to 15% for LPG, similar to the OEM vehicles. Ozone-forming potential was not calculated for these vehicles because of insufficient data.

Finally, the emissions testing, and the resultant effect on the environment, is a complex and evolving science. EPA recently implemented or proposed various changes to its standard test procedures to add cold temperature

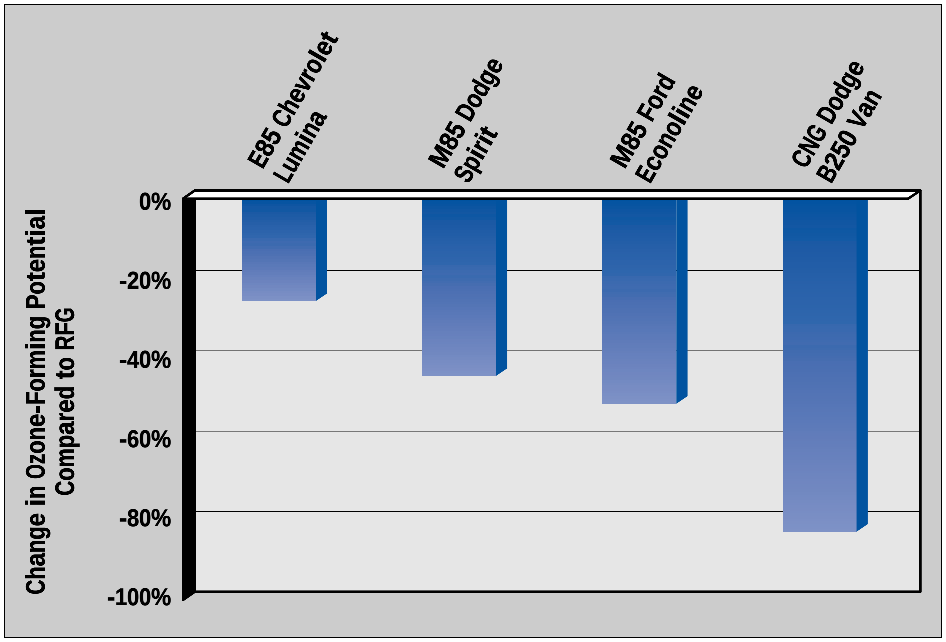


Figure 13. Ozone-forming potential of the various AFVs

Table 7. Emissions Test Results from CNG Conversions

Vehicle Model	Model Year	After Conversion (CNG) NO$_X$	CO	NMHC
Acclaim	1992	●	○	○
Acclaim	1992	●	◒	◒
Astro	1992	◒	●	◒
Caravan	1992	●	●	◒
Caravan	1992	●	●	◒
Safari	1993	◒	NC	○
Safari	1993	◒	◒	○
Taurus	1994	●	●	NC
Taurus	1994	●	●	NC
B250	1994	◒	◓	○
B250	1994	◒	●	○
C1500	1994	◒	●	○
C1500	1994	◒	●	○

○ Large emissions decrease (>50%)
◒ Moderate emissions decrease (10%–50%)
◓ Moderate emissions increase (10%–50%)
● Large emissions increase (>50%)

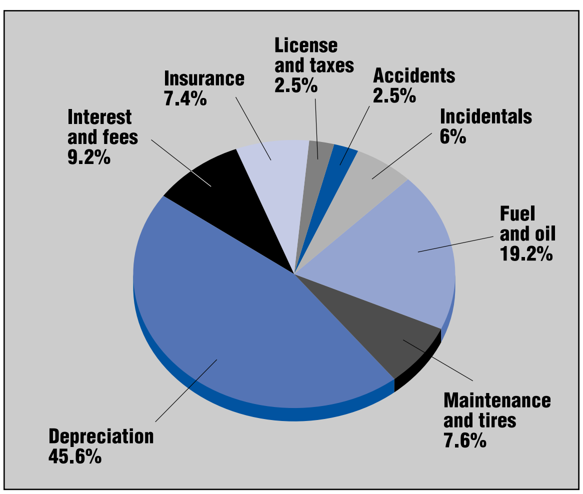
NC = No change (i.e., less than 10%)

testing and higher acceleration testing, two areas where gaseous-fueled vehicles are expected to excel. Testing is now being done to evaluate the performance of all the alternative fuels using these new procedures.

In summary, the test results show that AFVs have the potential to significantly reduce exhaust emissions and their impact on the environment, but this is not guaranteed. The technology used is as important as the fuel used, and fleets should be careful in their choice of vehicles if a main objective is to improve the environment.

Because of the disappointing performance of the aftermarket conversion kits cited, fleets considering conversions should require that they meet EPA's new standards. (*Standards for Emissions From Natural Gas-Fueled, and Liquefied Petroleum Gas-Fueled Motor Vehicle Engines and Certification Procedures for Aftermarket Conversions*, Federal Register, September 1994.)

Figure 14. Distribution of operating costs for composite U.S. fleet



Source: PHH Vehicle Management Services

Cost

Major vehicle costs associated with owning and operating any light-duty vehicle include the depreciation, fuel and oil, interest and fees, maintenance and tires, and insurance. The distribution of costs for operating a gasoline-fueled fleet vehicle are depicted in Figure 14. This distribution represents cost during the life of a vehicle, and is a composite average of fleets across the United States. These costs are based on a vehicle being in service an average of 27 months and having an average acquisition cost of $15,000. Differences such as self-insurance for government and some private fleets, and the methods of logging some types of maintenance and repairs, will affect the distribution of vehicle costs.

Costs associated with owning and operating vehicles significantly affect the likelihood that fleets or individuals will buy them. Distributions of cost are likely to be different for a fleet of AFVs than for a fleet of gasoline vehicles. Differences in initial acquisition costs (and therefore, depreciation), fuel costs, and maintenance are expected to affect the operation cost distribution for AFVs. Information on differences in AFV operation costs, including acquisition, fuel, and maintenance, are discussed in the sections that follow. A sample analysis that compares an AFV and gasoline vehicle operating costs is also included.

Additional Acquisition Cost

The information available to date on the AFVs in the Federal light-duty vehicle evaluation program indicates that AFV initial acquisition cost ranges up to 25% more than comparable gasoline vehicles. The difference is primarily due to modifications required to enable a gasoline model vehicle to operate on an alternative fuel, and the limited production of these vehicles. If more AFVs were produced, their initial cost would likely drop.

Price increases range from $0 to $800 for the FFVs, depending on the manufacturer. Most of the cost increase is due to the special fuel system materials required for the alcohol fuels.

For CNG vehicles, the acquisition cost has been as much as $5,000 more than a similar gasoline model since the Federal government started incorporating AFVs into its fleet. The bulk of the price increase is the result of the different fuel storage and delivery systems necessary to accommodate a gaseous fuel. As the demand for CNG vehicles increases production numbers, and manufacturers continue to optimize their designs, the price differential is expected to decrease. For example, one automobile manufacturer has announced a reduction of $750 in the CNG option price on its most popular CNG models in 1996.

The cost of aftermarket conversions of light-duty vehicles depends on the alternative fuel, the level of conversion technology, and the number and size of fuel tanks. The average total cost for each CNG conversion in our program has been about $4,500. Each propane conversion has run about $2,800. The CNG conversion cost is comparable to the premium charged for the CNG option package on an OEM vehicle. The biggest cost factor in CNG and propane conversions is the number and size of the fuel tanks that are installed. The fuel tanks used in each conversion depend on the vehicle type and the desired vehicle range.

As with standard gasoline models, acquisition price for any AFV will vary depending on the vehicle model and options. Although an unknown at this point, the resale market is expected to grow as the AFV market increases, thus enabling recovery of some of the additional acquisition costs.

Fuel and Oil Costs

Fluctuations in wholesale prices and differences in state and local tax structures result in a wide variation in retail fuel costs across the country. Wholesale fuel prices vary as much as $0.20 per equivalent gallon in various cities across the country. State and local taxes increase the variation in retail fuel prices to as much $0.40 per equivalent gallon of fuel across the United States. Some states and communities offer incentives to purchasers of alternative fuels that include reduced tax rates, taxing only the gasoline portion of an alcohol fuel, and taxing all fuels at the same rate as gasoline.

In early 1996, retail (pump) prices were approximately $1.62 to $1.72 per gallon of 85% ethanol (average price: $1.66/GGE); $1.73 to $2.69 per gallon of 85% methanol (average price: $2.00/GGE); $0.58 to $1.05 per gallon of CNG (average price: $0.86/GGE); and $1.06 to $1.18 for regular unleaded gasoline (average price: $1.13/gal.). All prices reflect conversion to GGE (or for an amount with the same energy content as one gallon of gasoline). A number of industry sources, including *Oxy-Fuel News*, *21st Century Fuels*, and

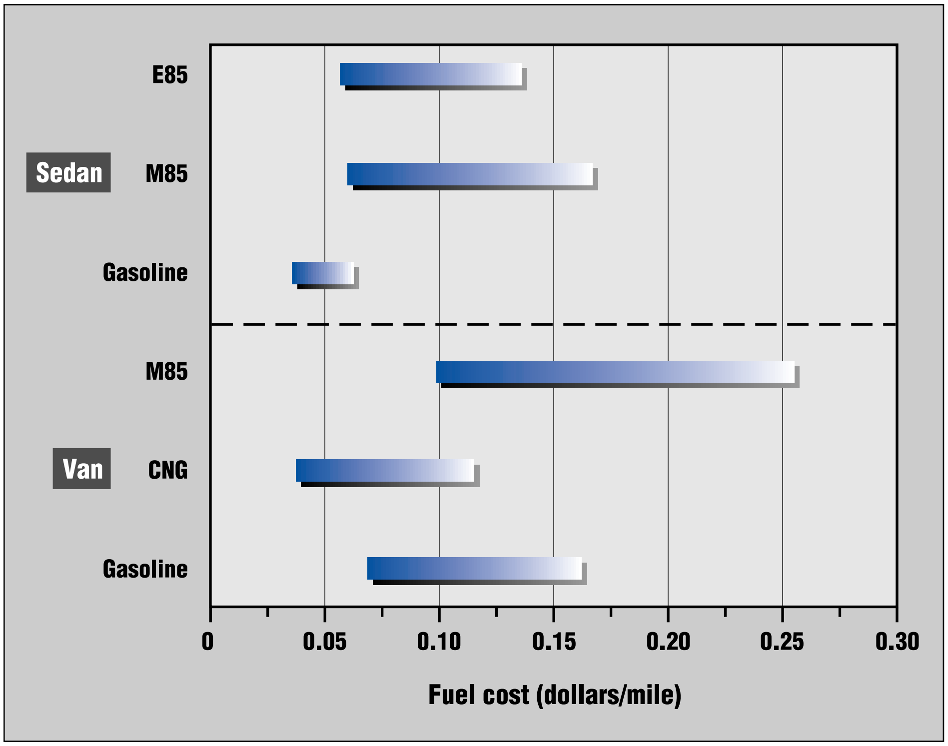


Figure 15. Range of fuel costs per mile (alternate fuel costs are based on GGE)

New Fuels Report, track the wholesale and retail prices of the various alternative motor fuels. DOE's Energy Information Administration also produces weekly and monthly publications with information on gasoline prices across the country.

Variations in fuel costs, combined with variations in fuel economy for the various vehicles, result in a wide range of fuel costs per mile driven. The ranges of fuel costs per mile for the AFVs and gasoline vehicles in the Federal test fleet are shown in Figure 15. The fuel cost per mile ranges were calculated using the variations in fuel price per equivalent gallon and range of fuel economy of each vehicle in the program. The average range of fuel cost per mile for ethanol and methanol sedans was somewhat higher than that for gasoline. Chevrolet Lumina and Ford Taurus sedans operated on ethanol; Luminas, Taurus, Dodge Spirit, and Dodge Intrepid sedans operated on methanol; and Lumina, Taurus, and Spirit sedans operated on gasoline. For vans, CNG is comparable to gasoline in range of fuel costs per mile, but methanol is somewhat higher. Vans in this analysis included Ford Econolines operating on methanol, Dodge Caravans and Ram vans operating on CNG, and Ford Econolines and Dodge Ram vans operating on gasoline. The actual cost per mile for any specific vehicle will be affected by factors such as the driving cycle of the vehicle, the driving style of the operator, the actual mpg level achieved by a vehicle, and the local cost of fuel.

Oil cost depends on the price and frequency of oil changes. Automobile manufacturers typically recommend oil change intervals of 7,500 miles or 6 months (whichever occurs first) for gasoline-fueled vehicles. Because alcohol fuels are corrosive, manufacturers recommend an oil change interval of 5,000 miles or 6 months (whichever occurs first) for FFVs operated on alcohol fuels. Because of these more frequent oil changes (requiring a special oil that costs more), typical oil costs are approximately 0.5 cents per mile for alcohol-fueled vehicles. This is higher than the 0.3 cents per mile cost for gasoline vehicles, based average oil change prices. Manufacturers recommend the same oil change interval for CNG-fueled vehicles as they recommend for gasoline-fueled vehicles. Therefore, assuming comparable prices, these vehicles will have similar oil costs. All vehicles in the Federal light-duty evaluation program have followed the manufacturer-recommended oil change intervals.

Maintenance Costs

The availability of maintenance cost information has been affected by a number of factors. First, much of the maintenance on the Federal test vehicles has been done under warranty at no cost to the fleet operator (except for lost time in service). Many unscheduled repairs on early AFVs were due to the developmental status of the fuel and control systems. Many fuel injection, fuel filter, and fuel pump problems in the 1991 M85 Luminas and Tauruses, and fuel injection, pressure regulator, line, and valve problems in the 1991 and 1992 CNG-fueled vehicles attest to this status. In addition, the increasing number and variety of vehicles in the study fleet made it difficult to collect detailed maintenance cost information. Finally, it is generally desirable to have large populations to calculate meaningful averages for maintenance costs. Because of these factors, data on the actual cost of maintenance, and a summary of maintenance cost per mile, are not available.

However, based on the experiences of this study, maintenance costs are expected to be marginally higher for AFVs than for gasoline vehicles for several reasons. Some parts cost more for vehicles in limited production, which is still the case for most AFV models. Some maintenance problems, and therefore costs, are unique to AFVs. For instance, although fuel pump and injector problems were common in the early models, they have decreased as manufacturers gained experience and improved AFV designs. Scheduled maintenance costs, specifically for oil changes, will continue to cost somewhat more for alcohol-fueled vehicles, because of the more frequent recommended oil change schedule.

The analysis of available maintenance data focused on the CNG- and methanol-fueled vehicles, because we lacked adequate data to analyze ethanol vehicles. The analysis focused on the number of unscheduled repairs as opposed to cost of repairs, for the reasons described above. The repair trends for CNG and M85 vehicles (Figure 8, page 11) clearly indicate that unscheduled maintenance has decreased with the newer model years. These trends and the growing experience with AFVs increase confidence that their long-term maintenance costs should, in time, approach the levels of gasoline vehicles.

Sample Operating Cost Comparison

At this point, we do not have enough cost information to do a detailed cost analysis based on the study vehicles in the Federal fleet. However, we have included the results of a sample calculation that includes the major vehicle operation cost factors and provides a first-order comparison of operating costs between an AFV and a gasoline-fueled vehicle. This sample analysis was provided by PHH Vehicle Management Services, whose expertise includes fleet data collection and analysis.

The analysis provides a simple comparison between annual operating

Table 8. Assumptions Used in Sample Analysis

Vehicle Acquisition Information	
Capital costs (gasoline)	$14,000
Alternative fuel—CNG option cost	$4,000
Alternative fuel capital costs	$18,000
Assumptions	
Gasoline price (per gallon)	$1.19
Miles per gallon rating (mpg)	23
Alternative fuel—equivalent gallon price	$0.80
Expected resale value	~40%*
Vehicle life	36 months

* Resale value decreases with increased vehicle mileage, approximately $300 per additional 5,000 miles

Table 9. Annual Operating Costs (with gasoline at $1.19 per gallon)

	2,100 mi/mo	3,000 mi/mo	3,500 mi/mo
Gasoline vehicle			
Fuel	$1,303.83	$1,862.61	$2,173.04
Maintenance	$550.00	$550.00	$550.00
Depreciation	$2,800.00	$3,000.00	$3,100.00
Annual Total	$4,653.83	$5,412.61	$5,823.04
Cost per Mile	18.5 cents	15.0 cents	13.9 cents
CNG vehicle			
Fuel	$876.52	$1252.17	$1460.86
Maintenance	$550.00	$550.00	$550.00
Depreciation	$3,600.00	$3,800.00	$3,900.00
Annual Total	$5,026.52	$5,602.17	$5,910.86
Cost per Mile	19.9 cents	15.6 cents	14.1 cents
Differential Cost per Mile of a CNG Vehicle	1.4 cents	0.6 cents	0.2 cents

costs of an AFV and a gasoline vehicle, including the primary economic factors that a fleet operator would need to consider. CNG is used as the alternative fuel in this sample analysis. The assumptions used in this analysis are listed in Table 8 (insurance, interest, fees, taxes, and incidentals are not included). No costs are included for a site requiring a refueling station. Table 9 shows the resulting annual operating cost for a gasoline and a CNG vehicle with monthly mileage accumulations of 2,100; 3,000; and 3,500 miles. The maintenance costs were assumed to be the same for both fuels. Based on the performance and reliability trends in the Federal fleet, this assumption appears reasonable. Table 10 shows the results when the price of gasoline is increased to $1.25 per gallon. The economics are highly dependent on the price of gasoline, and can be affected by the vehicle's fuel economy. In general, as the mileage increases, CNG-fueled vehicles become more economical. Similar comparisons could be done for other alternative fuels by substituting the appropriate vehicle and fuel cost information and assumptions.

As described, this sample analysis provides a simple first-order comparison of AFV and gasoline vehicle costs, including the primary factors that affect fleet economics. Clearly there are many other factors to consider when adding AFVs to a fleet. For instance, economies of scale, which would affect vehicle purchase price and other assumptions, may be available to a fleet. The fueling infrastructure can significantly affect cost.

Infrastructure costs include everything from building a fueling station to personnel and operational readiness for alternative fuels. The fueling facility costs will vary with the fuel used and how it is provided (e.g., on-site central fuel station). A small portable ethanol or methanol station may cost a few thousand dollars; a large permanent CNG refueling station may cost hundreds of thousands of dollars. Personnel costs are generally associated with driver training, maintenance, and security, and staff member safety. Operational readiness includes vehicle storage. Indoor storage of CNG vehicles may require building modifications such as upgrades to ventilation systems. These are all examples of other considerations that are part of the economics of incorporating AFVs into a fleet. A more detailed study of fleet economics, based on results of the CleanFleet project (see *For Additional Information* on page 27), presents a fairly comprehensive consideration of the factors that affect AFV costs for a fleet.

Government incentives can significantly reduce the incremental costs of AFVs. Under the Energy Policy Act of 1992, the Federal government allows a maximum tax deduction of $2,000 for the incremental costs of AFVs up to 10,000 lb gross vehicle weight. Many states offer incentives for purchasing dedicated or converted AFVs, including income tax credits, special or reduced fuel excise tax on the alternative fuel, reduced sales tax on fuel and conversion equipment, rebates on costs of converting vehicles, and low-interest loans for purchasing AFVs. Fleet operators should contact their state energy office for information on incentives available in their state.

Table 10. Annual Operating Costs (with gasoline at $1.25 per gallon)

	2,100 mi/mo	3,000 mi/mo	3,500 mi/mo
Gasoline vehicle			
Fuel	$ 1,369.57	$1,956.52	$2,282.61
Maintenance	$550.00	$550.00	$550.00
Depreciation	$2,800.00	$3,000.00	$3,100.00
Annual Total	$4,719.57	$5,506.52	$5,932.61
Cost per mile	18.7 cents	15.3 cents	14.1 cents
CNG vehicle			
Fuel	$876.52	$1252.17	$1460.86
Maintenance	$550.00	$550.00	$550.00
Depreciation	$3,600.00	$3,800.00	$3,900.00
Annual Total	$5,026.52	$5,602.17	$5,910.86
Cost per mile	19.9 cents	15.6 cents	14.1 cents
Differential Cost per Mile of a CNG Vehicle	1.2 cents	0.3 cents	0.0 cents

Other Information

Data Collection Experience

This data collection project has been extremely challenging, and has provided many lessons about how future programs should be designed. It was difficult to keep drivers interested in filling out data cards, particularly for the extended time periods we required, and some organizations and manufacturers have resisted disclosing information. Federal employees were burdened with completing data collection cards, with no incentive for the extra effort. On the other hand, we experienced extraordinary participation from a number of sites, including some that provided data voluntarily. The project size and variety of vehicles made focusing on a controlled set of data collection vehicles and a consistent data collection method difficult. Vehicles were operated under random driving patterns, in various areas across the country. This dramatically increased the effort required to achieve continuity among details of data collection.

Some early prototype AFVs were placed in service while still undergoing development. These vehicles had reliability problems in service: even though successive models were greatly improved, the earliest impressions of AFVs lingered. Failure in service ranged from vehicles running out of fuel in the California desert because of faulty fuel gauges, to vehicles not starting in less than ideal urban neighborhoods. Some agencies are reluctant to operate AFVs because of these early experiences.

Finding FFVs that were actually being operated on an alternative fuel was difficult, partly because of the lack of infrastructure, which resulted in the alternative fuel refilling stations being less conveniently located than gasoline stations. And, as mentioned earlier, many vehicles in this program accumulated mileage very slowly.

Our experiences in these data collection efforts have led to a number of ideas for changing future data collection efforts. We believe the following modifications would improve future data collection efforts:

- Smaller fleet size (< 50 vehicles, especially for detailed data collection)
- Match vehicle range and utility to fleet needs (where possible)
- Establish agreements with maintenance and repair shops to obtain detailed repair records and cost information
- Work with sites that have convenient refueling
- Work with fleets that accumulate mileage rapidly, to reduce the time needed to collect data.

These are some of the criteria we plan to include in our future data collection efforts. The ultimate goal continues to be high-quality data on AFV performance and characteristics, with evaluation results available in a timely manner.

Other Information Sources

To enable access to data being collected in the light-duty AFV program, and other alternative fuel demonstration programs, DOE established the AFDC at NREL. The AFDC stores all the light-duty vehicle data in a database, and information is available to anyone, free of charge. The AFDC can be accessed via the World Wide Web on the Internet, using browser software such as Mosaic or Netscape (at ***http://www.afdc.doe.gov***).

The National Alternative Fuels Hotline is a DOE source of information concerning alternative fuels and related issues. The Hotline staff can answer questions about alternative fuels, process requests for information, or refer callers to other data sources or organizations. The Hotline can be reached at ***1-800-423-1DOE (1363)***.

Additional, more detailed reports are available on the OEM and conversion emissions results. Three Society of Automotive Engineers (SAE) papers on OEM emissions results, plus a more detailed report on the conversion experiences, are available. Call the Hotline at 1-800-423-1DOE, or access our World Wide Web site at ***http://www.afdc.doe.gov***.

Acknowledgment

NREL wishes to extend thanks to the many Federal government agencies, and particularly the drivers of the vehicles in our study fleet, for their participation in this vehicle evaluation effort. NREL would also like to acknowledge Patrick McConnell and Bill Rivers of GSA in Washington, D.C., and other regional GSA personnel who have provided a wide range of information on the AFVs in the GSA fleet, including sharing vehicle maintenance records.

For Additional Information. . .

Visit our World Wide Web site at ***http://www.afdc.nrel.gov*** or call the National Alternative Fuels Hotline at ***1-800-423-1DOE***. Selected citations are shown below as examples of the types of information you can find on the Web or through the Hotline (refer to AFDC accession numbers, NREL numbers, or SAE numbers when calling the Hotline; Web searches can be performed by key word, author, or title, for example).

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